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PECULIARITIES OF TRANSPORTATION OF GRAIN PRODUCTS BY CONVEYOR SPIRALS

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Under the current conditions of price growth, the expansion of agricultural enterprises and the creation of new ones based on them, the economic feasibility and practical possibility of purchasing the necessary equipment has significantly decreased. In connection with this and with the aim of expanding the functional capabilities of the technical means available in farms, the application of devices to serial machines is becoming more and more effective. The article presents an overview of modern attached screw equipment for quick unloading of motor vehicles. When designing screw equipment, it is necessary to take into account the peculiarities of their transport properties. The transportation of bulk goods by angle screw equipment depends on the frequency of rotation and the level of filling of the conveyor with the product. Structural and mechanical properties primarily depend on the density of packing of particles of loose material, their relative mobility. The mechanical properties of such a structure can be described by the equivalent modulus of elasticity and the equivalent Poisson's ratio. The nature of energy transfer in a loose material is largely determined by the forces of friction and adhesion at the points of contact of its particles. A characteristic feature of screw conveyors is that the screw working body is freely (without supports) located in an elastic or rigid casing and along its inner surface transports the material to the unloading area. The article presents the main theoretical ratios for determining the effectiveness of hinged screw products. A study was conducted to determine the influence of the main technical parameters on the performance of high-speed conveyors at a large angle.

Key words: *screw conveyor, grain product, productivity, rotation frequency, friction coefficient, slope.*
F. 21. Fig. 5. Ref. 10.

1. Analysis of last researches and publications

High angle screw conveyors for transporting bulk agricultural produce are the same in structure and principle of operation as screw conveyors for vertical lifting. They are used for the mechanization of transshipment operations with bulk goods and can be stationary, mobile, and mounted on vehicles. [1, 2, 3].

The productivity of such conveyors is 60...200t/h, the maximum productivity of the equipment in Western European countries reaches 350...400t/h. The highest grain drop height is 6.5 m.

2. Problem formulation

Many Western countries manufacture mounted screw products for quick unloading of vehicles.

The company "Fliegt" (Germany) produces tractor trailers for the transportation and transshipment of grain and mineral fertilizers, which are equipped with a replaceable screw side to the tractor trailer ASW "Gigant", a metal screw with the diameter of 450 mm, productivity of 350 t/h, a reloading height of 4.5 m. The screw folds and unfolds with a hydraulic drive, driven by the tractor's power take-off.

The company "Pronar" (Poland) offers loaders for transportation of grain and corn from harvesters to trucks with simultaneous weighing. They are equipped with mounted foldable high-speed screw conveyors (Fig. 1. a). Productivity of the screw conveyors is within 200...400 t/h.

Thanks to fast unloading, such reloaders can save up to 30% of the harvester's operation time. The company "Pronar" manufactures two models of reloaders - T740 with a carrying capacity of 15.3 tons and

T743 with a carrying capacity of 23 tons (Fig. 1. b).

The manufacturer of similar products in Ukraine is "Zavod Kobzarenko". Currently, the core business of the plant is manufacturing and sales of 15 types of tractor trailers and a wide range of screw products, such as reloading storage hopper PBN-20/1 (ПБН-20/1), PBN-16/2 (ПБН-16/2), PBN-30/2 (ПБН-30/2) (Fig. 1. c). The plant also manufactures the following screw products: foldable screw RSh-200/4.2 (РШ-200/4,2); hydraulic foldable screw GRSH-300/4.2 (РШ-200/4,2) (Fig. 1. d); foldable screw RSh-250/4.5 (РШ-250/4,5) for KamAZ vehicles, etc.

a *b* *c* *d*

Fig. 1. Tractor vehicles equipped with unloading high-speed conveyors: a) tractor-trailer ASW "Gigant" by "Fliegt" (Germany); b) reloader T743 by "Pronar" (Poland); c) reloading storage hopper PBN-30/2, Kobzarenko plant (Ukraine); d) Hydraulic foldable screw GRSH-300/4.2 Kobzarenko plant (Ukraine)

3. Aim of the researches

In order to increase the operational and functional capacity of the high angle screw conveyors, rational technological and technical parameters should be substantiated and confirmed by experimental studies

4. Results of the researches

Presentation of basic material of the research. When designing such conveyors, the peculiarities of their transport properties are taken into account. In contrast to the low angle screw conveyors, the ability of transporting bulk products by a high angle screw conveyor depends on the rotation frequency and on the cargo fill-up level of the conveyor casing [5, 7].

The general productivity formula can be theoretically described as:

$$П_т = \rho \cdot A \cdot \upsilon_п, \qquad (1)$$

where A – cross-sectional area of the flow, m^2; ρ – specific weight of the cargo; $\upsilon_п$ – axial velocity of the material, m/s.

The screw transportation process is influenced by: screw rotation frequency; screw inclination K_β = 1.0...0.3; the method of loading and unloading is taken into account by the coefficients K_z = 1.0...0.5, K_r = 1.0...0.94.

Effective volume of material per pitch:

$$V_д = A \cdot S = \psi \cdot V, \quad (2)$$

where A – cross-sectional area of the flow, m^2; S – pitch ratio; ψ = 0,2…0,9 – filling factor; V – gutter volume per pitch.

$$V = 0{,}25\pi \cdot \left(D^2 - d^2\right) \cdot S, \quad (3)$$

where D – screw diameter, m; d – shaft diameter, m.

After relevant substitutions and transformations, we get the movement speed with known geometric and technical parameters of the screw conveyor:

$$V_п = \frac{4П}{\pi \cdot K_п \cdot K_з \cdot \psi \cdot \rho \cdot (D^2 - d^2)}, \quad (4)$$

where П – productivity, t/s; ρ – the cargo's bulk density, t/m^3.

At the inclinations of the conveyor to the horizon (45°...70°) and its partial fill-up, the particles of the bulk product at a low speed of rotation of the screw create a complex movement, detaching from the casing and the screw surface and do not move in the direction of transportation.

At the inclinations β > 40°...45°, it is irrational to use screw conveyors with a low screw speed, as this significantly reduces productivity and too much power is spent on mixing and grinding the cargo.

The smallest rotary speed of the screw ω, at which cargo transportation is possible with any filling factor, can be determined by the formula [4]:

$$\omega_k = \sqrt{\frac{-g\cos\left(\frac{\beta}{0{,}75} + \alpha + \rho_в\right)}{r \cdot \mu_к \cos\left(\alpha + \rho_в\right)}}, \quad (5)$$

where β – inclination of the conveyer; α – pitch angle; $\rho_в$ – friction angle between the cargo and the screw surface; $\mu_к$ – friction ratio between the cargo and the case; r – outer radius of the screw; g – 9,81 m/s^2 - acceleration of gravity.

With greater filling of the casing, or an increase in the rotation frequency of the screw, the cargo particles pressed against its inner surface move along the casing in spiral trajectories. If the inclinations β > 70°, then the cargo particles always move without breaking away from the casing and the screw surface, but the transportation is also partial; it occurs only with almost full fill-up. With this type of fill-up the cargo layer, which is located near the outer diameter of the screw, is more strongly pressed against the casing and, while sliding along the screw surface, moves along with it.

The filling factor of the screw conveyor casing ψ can be determined by the curves (Fig. 2), which characterize the dependence of the factor ψ on the angle of inclination of the conveyor β and the centrifugal force for bulk goods [2].

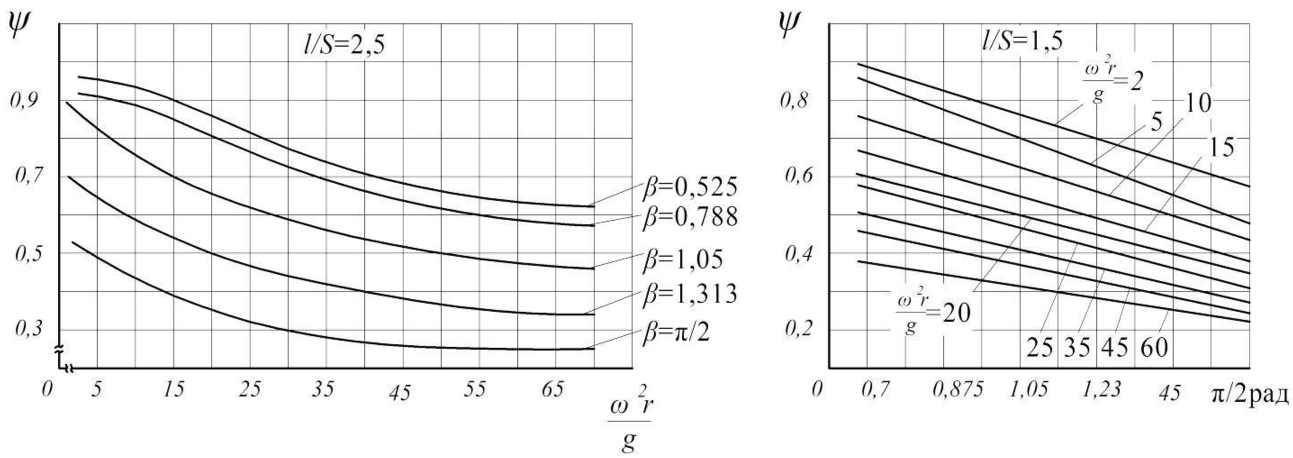

Fig. 2. Dependence of the filling factor ψ of a high angle screw conveyor on the inclination of the conveyor β and centrifugal forces (presented as a function of $\frac{\omega^2 r}{g}$)

Basic Theoretical Correlations. Let's consider the speeds at which the cargo is forced to move.

Let's determine the absolute υ_a, rotational speed $\upsilon_в$ (Fig. 2.), as well as the speed of movement (assuming that the load is concentrated at point A) [4, 6].

$$\upsilon_a = \frac{\upsilon_n}{\cos\varepsilon}. \quad (6)$$

$$\upsilon_в = \upsilon_n\ tg\varepsilon, \qquad (7)$$

E is the trajectory inclination of the absolute motion of the cargo to the generator of the cylindrical casing of the screw passing through point A.

We assume that the cargo is uniformly concentrically placed in the conveyor pipe.

To determine the angle ε, let's consider the balance of forces applied to particle A (Fig. 3) placed in the lower part on the surface of the casing at an arbitrary angle φ from the normal to the direction of cargo transportation:

$$\begin{cases} F_K \cdot \sin(\varepsilon\text{-}\alpha) = mg \cdot \sin\beta \cdot \sin\alpha - mg \cdot \cos\beta \cdot \sin\varphi \cdot \cos\alpha + F_T \\ F = F_K \cdot \cos(\varepsilon\text{-}\alpha) + mg \cdot \sin\beta \cdot \cos\alpha + mg \cdot \cos\beta \cdot \sin\varphi \cdot \sin\alpha \end{cases}, \qquad (8)$$

where β – conveyer's inclination to the horizon, degrees.

By substituting the values $F_T = f \cdot F$, and taking out the force F, we obtain:

$$F_K = \frac{m \cdot g \cdot \sin(\alpha + p) \cdot \sin\beta - m \cdot g \cdot \cos(\alpha + p) \cdot \cos\beta \cdot \sin\varphi}{\sin(\varepsilon - \alpha - p)}. \qquad (9)$$

On the other hand the force F_K, can be written with the following equation:

$$F_K = \frac{f \cdot m \cdot \upsilon_n^2 tg^2\varepsilon}{R} + f \cdot m \cdot g \cdot \cos\beta \cdot \cos\varphi. \qquad (10)$$

The maximal value of the force F_K will be at φ = 0. Then, by equating the right sides of these equations we obtain:

$$\frac{f \cdot \upsilon_n^2 \cdot tg^2\varepsilon}{R} + f \cdot g \cdot \cos\beta = \frac{g \cdot \sin(\alpha + p) \cdot \sin\beta}{\sin(\varepsilon - \alpha - p)}. \qquad (11)$$

We modify the Equation (11) to look as follows:

$$\upsilon_n = ctg\varepsilon \sqrt{R \cdot g \left[\frac{\sin(\alpha + p) \cdot \sin\beta}{f \cdot \sin(\varepsilon - \alpha - p)} - \cos\beta\right]}. \qquad (12)$$

In equation (12), the value of the angle ε is unknown. It is easy to determine by the method of successive approximations

By substituting different values of the angle ε into equation (12), we can achieve the equality of the left and right sides, while the initial value of the angle ε can be taken as:

$$\varepsilon = \alpha + p + 30°. \qquad (13)$$

$$\begin{cases} F_K \cdot \sin(\varepsilon\text{-}\alpha) = mg \cdot \sin\beta \cdot \sin\alpha + F_T \\ P = F_K \cdot \cos(\varepsilon\text{-}\alpha) + mg \cdot \sin\beta \cdot \cos\alpha \end{cases}, \qquad (14)$$

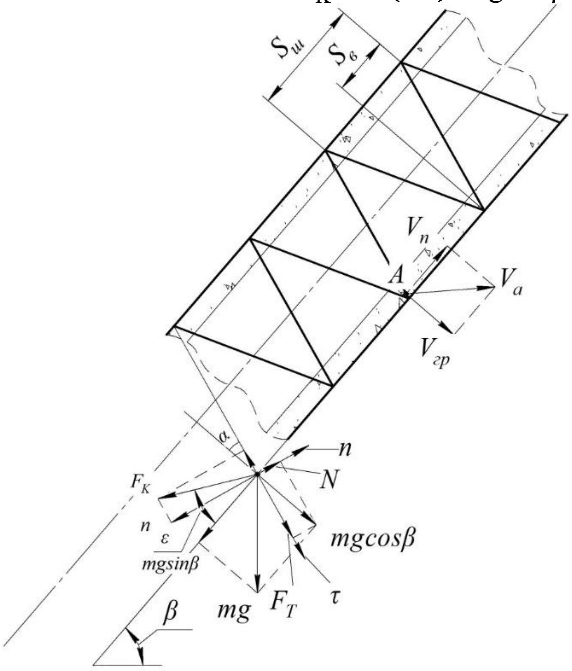

Fig. 3. Schemes of forces acting on a particle of cargo for a high angle high-speed conveyor

By substituting $F_T = f\,P$ and deleting the force P from this equations, we obtain:

$$F_K = \frac{m \cdot g \cdot \sin(\alpha + p) \cdot \sin\beta}{\sin(\varepsilon - \alpha - p)}. \qquad (15)$$

The value of the force F_K can be expressed from the equation:

$$F_K = \frac{f \cdot m \cdot \upsilon_n^2 \cdot tg^2\varepsilon}{R} + f \cdot m \cdot g \cdot \cos\beta \qquad (16)$$

By equating the right sides of these equations and shortening by m, we obtain:

$$\frac{f \cdot \upsilon_n^2 \cdot tg^2\varepsilon}{R} + f \cdot g \cdot \cos\beta = \frac{g \cdot \sin(\alpha+p) \cdot \sin\beta}{\sin(\varepsilon - \alpha - p)} \qquad (17)$$

By solving υ_n we obtain:

$$\upsilon_n = ctg\varepsilon \sqrt{R \cdot g \left[\frac{\sin(\alpha+p) \cdot \sin\beta}{f \cdot \sin(\varepsilon - \alpha - p)} - \cos\beta\right]}. \qquad (18)$$

After we determine the angle ε.

According to equations (6) and (7), we determine the speed υ_a and $\upsilon_в$.

The number of the screw rotations and the rotary speed can be determined by the formulas

$$n = \frac{60 \cdot \upsilon}{\pi \cdot D}. \qquad (19)$$

$$\omega = \frac{\pi \cdot n}{30}, \qquad (20)$$

where ω – circular speed at the edge of the screw.

$$\upsilon = \upsilon_n(ctg\alpha + tg\varepsilon), \qquad (21)$$

where υ_n – the speed of moving the cargo along the axis of the screw.

The results of the calculations and research.

Having carried out the appropriate calculations according to the described methodology, it can be stated that for the high angle screw high-speed conveyor, which is shown in fig. 1.b, the productivity is 60t/h, and the cargo delivery height is 2.5m, with the inclination of the track β = 60°, the following results were obtained during the transportation of wheat:

- external diameter of the screw D = 300mm;
- screw shaft diameter d = 60mm;
- the speed of cargo movement along the axis of the screw is 0.7 m/s
- critical rotary speed ωk = 11.87 s^{-1};
- circular speed at the edge of the screw = 4.02 m/s;
- the actual number of the screw rotations= 256 min^{-1};
- actual rotary speed ωf = 26.79 s^{-1};
- the power used to move the load – 1,78 kWt

To determine the influence of the main technical parameters on the performance of high angle high-speed screw conveyors, studies were conducted, the results of which are presented in Fig. 4 and Fig. 5

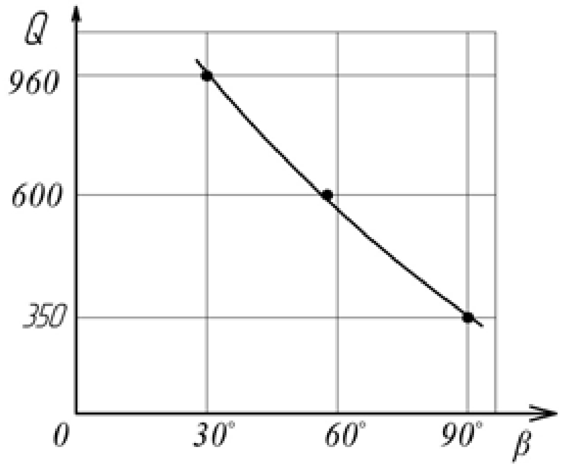

Fig. 4. Dependence of productivity Q on the angle of inclination of the screw β at the number of rotations of the screw = 256 min^{-1}

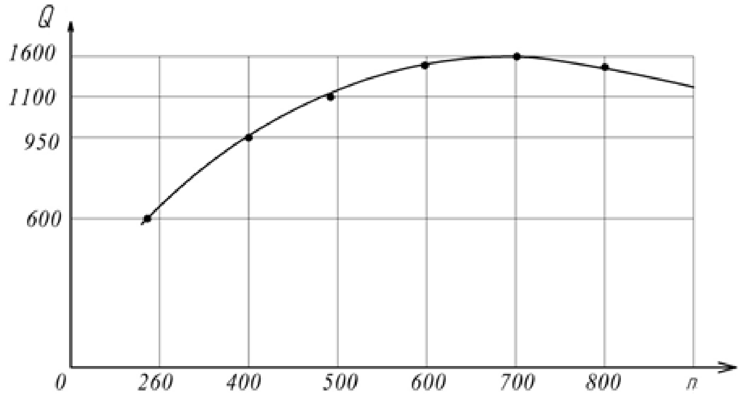

Fig. 5. Dependence of productivity Q on the rotation frequency of the screw at the angle of inclination of the screw β = 60°

On the basis of the obtained results (Fig. 4), we can conclude that with an increase in the angle of inclination from 30° to 90°, the productivity decreased by approximately 2.75 times, at a rotation frequency of the screw surface of 256 rpm. This can be explained by the fact that the load moves along a helical trajectory with a smaller pitch than the pitch of the screw itself. In reality though, the trajectory is more complex, as the cargo is heterogeneous, partially mixed and unevenly loaded through the neck.

On the basis of the obtained results (Fig. 5) we can conclude that with an increase in the rotation frequency, the productivity initially increases to a certain value, and then partially decreases, for example, for wheat grain, the productivity increases to a frequency of approximately 700 rpm, at an angle of inclination β = 60°, and then decreases. This can be explained by the fact that at high rotary speeds the grain is thinned by air and moves more.

5. Conclusions

1. High angle screw conveyors with a slow rotation of the screw can transport bulk cargo when the conveyor casing is filled at a certain rate;
2. At the angles of β > 35...45°, it is impractical to use screw conveyors with a low rotation speed, because of decrease in productivity, and the power is partially spent on moving and grinding products;
3. The critical rotation frequency of the screw, at which it is possible to lift the cargo particles for high angle screw conveyors, is determined by the formula (3);
4. The movement of cargo particles along the screw axis depends on many factors: speed increases; with an increase in the lift angle of the screw; with a decrease in the screw radius; with a decrease in the friction ratio between the parts of the cargo and the screw, and with an increase in the friction ratio between the particles of the cargo and the casing wall

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ОСОБЛИВОСТІ ТРАНСПОРТУВАННЯ ЗЕРНОВОЇ ПРОДУКЦІЇ ГВИНТОВИМИ КОНВЕЄРАМИ

За нинішніх умов зростання цін, розширення сільськогосподарських підприємств і створення на їх основі нових значно знизилась економічна доцільність та практична можливість придбання необхідної техніки. У зв'язку з цим та з метою розширення функціональних можливостей наявних у господарствах технічних засобів все ефективнішим стає застосування пристроїв до серійних машин.

У статті представлений огляд сучасного навісного шнекового обладнання для швидкого розвантаження автотранспорту. При проектуванні шнекового обладнання необхідно враховувати особливості їх транспортних властивостей. Транспортування сипучих вантажів кутовим шнековим обладнанням залежить від частоти обертання та від рівня заповнення конвеєра продуктом.

Структурно-механічні властивості насамперед залежать від щільності укладання часток сипкого матеріалу, відносної їх рухливості. Механічні властивості такої структури можна описати еквівалентним модулем пружності та еквівалентним коефіцієнтом Пуассона. Характер передачі енергії в сипкому матеріалі значною мірою визначається силами тертя та зчеплення в місцях контактів його часток. Характерна особливість гвинтових конвеєрів полягає у тому, що гвинтовий робочий орган вільно (без опор) розташовується у еластичному або жорсткому кожусі та по його внутрішній поверхні транспортує матеріал у зону вивантаження.

Представлені в статті основні теоретичні співвідношення для визначення ефективності навісних гвинтових виробів. Проведено дослідження щодо визначення впливу основних технічних параметрів на продуктивність високошвидкісних конвеєрів під великим кутом.

Ключові слова: *шнековий конвеєр, зернопродукт, продуктивність, частота обертання, коефіцієнт тертя, нахил.*

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